

The colonization of maize seedling roots and rhizosphere by *Fusarium* spp. in Mississippi in two soil types under conventional tillage and no-tillage systems

Colonisation des racines et de la rhizosphère de semis de maïs par des *Fusarium* spp. dans deux types de sol du Mississippi dans des systèmes avec travail du sol classique et sans travail du sol

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Résumé de l'article

De 1995 à 1997, le maïs hybride Pioneer 3167 a été semé annuellement à quatre dates dans deux types de sol du Mississippi et échantillonné hebdomadairement de une à quatre semaines après le semis. Les parcelles ont été labourées avec un outil aratoire multi-fonctions et les rangs formés à l'automne, ou n'ont pas été travaillées avant le semis direct du printemps. Avec le labour, les *Fusarium* spp. ont été isolés plus fréquemment pour les dates de semis les plus précoces et les plus tardives et pour un échantillonnage après 10 et 17 jours. Pour les parcelles sans travail du sol, les fréquences d'isolement étaient globalement plus faibles que pour les parcelles avec travail du sol classique et déclinaient avec l'avancée des dates de semis et l'allongement de la période entre le semis et l'échantillonnage. Les populations de *Fusarium* les plus élevées ont été trouvées dans la rhizosphère dans des parcelles avec travail du sol classique dont le sol était un limon siliceux et avec l'échantillonnage fait 28 jours après la deuxième plantation de 1997; les populations les plus faibles provenaient d'un sol limono-argileux. Le *F. moniliforme*, le *F. solani* et le *F. oxysporum* ont été les principales espèces de *Fusarium* isolées des racines de semis de maïs. Dans des essais de pathogénicité, le *F. moniliforme* et le *F. solani* ont eu des effets mesurables sur des semis de maïs. Le *F. moniliforme* a réduit la longueur des racines principales et a réduit le nombre de racines secondaires alors que le *F. solani* a réduit la masse sèche des racines de semis de maïs.

The colonization of maize seedling roots and rhizosphere by *Fusarium* spp. in Mississippi in two soil types under conventional tillage and no-tillage systems

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Pioneer 3167 hybrid maize was planted on two soil types in Mississippi on four dates annually from 1995 to 1997 and was sampled at weekly intervals beginning one week and ending 4 weeks after planting. Plots were either tilled with a do-all and rows formed in the fall or were left undisturbed until planting in the spring. Under tillage, *Fusarium* spp. were isolated most frequently at the earliest and latest planting dates when seedlings were sampled at 10 and 17 days. In no-tillage plots, the overall isolation frequency was lower than in conventional-tillage plots and decreased with later planting dates and sampling times. The highest *Fusarium* populations were found in the rhizosphere of a silt loam in conventional-tillage plots when seedlings were sampled 28 days after the second planting in 1997, compared to populations from a silty clay soil. *Fusarium moniliforme*, *F. solani* and *F. oxysporum* were the predominant *Fusarium* spp. isolated from maize seedling roots. In pathogenicity tests, *F. moniliforme* and *F. solani* produced measurable effects on maize seedlings. *F. moniliforme* reduced the length of primary roots and decreased the number of secondary roots, and *F. solani* reduced root dry weight of maize seedlings.

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De 1995 à 1997, le maïs hybride Pioneer 3167 a été semé annuellement à quatre dates dans deux types de sol du Mississippi et échantillonné hebdomadairement de une à quatre semaines après le semis. Les parcelles ont été labourées avec un outil aratoire multi-fonctions et les rangs formés à l'automne, ou n'ont pas été travaillées avant le semis direct du printemps. Avec le labour, les *Fusarium* spp. ont été isolés plus fréquemment pour les dates de semis les plus précoces et les plus tardives et pour un échantillonnage après 10 et 17 jours. Pour les parcelles sans travail du sol,

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les fréquences d'isolement étaient globalement plus faibles que pour les parcelles avec travail du sol classique et déclinaient avec l'avancée des dates de semis et l'allongement de la période entre le semis et l'échantillonnage. Les populations de *Fusarium* les plus élevées ont été trouvées dans la rhizosphère dans des parcelles avec travail du sol classique dont le sol était un limon siliceux et avec l'échantillonnage fait 28 jours après la deuxième plantation de 1997; les populations les plus faibles provenaient d'un sol limono-argileux. Le *F. moniliforme*, le *F. solani* et le *F. oxysporum* ont été les principales espèces de *Fusarium* isolées des racines de semis de maïs. Dans des essais de pathogénicité, le *F. moniliforme* et le *F. solani* ont eu des effets mesurables sur des semis de maïs. Le *F. moniliforme* a réduit la longueur des racines principales et a réduit le nombre de racines secondaires alors que le *F. solani* a réduit la masse sèche des racines de semis de maïs.

INTRODUCTION

Seedling diseases of maize (*Zea mays* L.), including seed rot, seedling blight, and root rot, are caused by seed- and soilborne fungi. Initial symptoms of seedling disease usually are small, reddish-orange lesions on the seminal root. As plants mature, lesions on secondary roots enlarge with time and ultimately affect the main roots. *Fusarium* spp. associated with seedling blight of maize are widely distributed in the United States (Farr *et al.* 1989; Futrell and Kilgore 1969; Hornby and Ullstrup 1967; Kingsland and Wernham 1962; Kommedahl *et al.* 1979; Leslie *et al.* 1990; Nelson *et al.* 1993). Among the *Fusarium* spp. known to colonize maize roots, *Fusarium moniliforme* J. Sheld., *Fusarium oxysporum* Schlechtend.:Fr., *Fusarium proliferatum* (T. Matsushima) Nirenberg, and *Fusarium solani* (Mart.) Appel & Wollenw. emend. Snyder & Hans. were considered as "rhizosphere competent" (O'camb and Kommedahl 1994). These species grow saprophytically, reproduce in the rhizosphere, and cause root rot when host plants are under stress (Young and Kucharek 1977). *Fusarium* spp. are also seedborne in maize (Daniels 1983) and may cause seed rot and seedling blight (Kommedahl and Windels 1981; Lipps and Deep 1991; Tuopay and Trevathan 1989).

Fusarium moniliforme is the most commonly reported fungal species causing seedling blight and root rot of maize (Foley 1962; Kommedahl and Windels

1981; Kommedahl *et al.* 1979; Whitney and Mortimore 1957). It has been reported that *F. moniliforme* colonizes maize plants systemically (Foley 1962), and infected tissues may rot or remain asymptomatic (Koehler 1942). However, Kucharek and Kommedahl (1966) demonstrated that systemic growth in corn tissue by *F. moniliforme* was localized rather than throughout the plant. *Fusarium moniliforme* also is the most common contaminant of commercial maize seed (Anderegg and Guthrie 1981; Edwards 1936). Seedborne inoculum causes seedling blight when climatic conditions are not optimal for seed germination and seedling growth. *Fusarium moniliforme* was the primary pathogen contributing to stand reduction in commercial maize fields in Mississippi (Futrell and Kilgore 1969); *Gibberella fujikuroi* (Sawada) Ito in Ito & Kimura (anamorph: *F. moniliforme*) and *Gibberella zeae* (Schwein.) Petch (anamorph: *Fusarium graminearum* Schwabe) were reported to cause seed rot, seedling blight, and Fusarium blight (Parris 1959).

Tillage systems were reported to affect the colonization of maize roots by *Fusarium* spp. (Koehler 1942). In Delaware, *Fusarium* spp. were isolated more frequently from rotted maize stalks from conventional-tillage fields than from stalks collected in no-tillage fields (Byrnes and Carroll 1986). In rotation-tillage plots in Illinois, stalk rot was lowest in no-tillage plots with continuous maize and in maize-soybean rota-

tion compared to conventional, ridge-subsoil, sweep plow, and disk-tillage (Hartman *et al.* 1983).

The objectives of this study were to determine the occurrence and pathogenicity of *Fusarium* spp. colonizing maize seedling roots over multiple growing seasons, on two soil types and under conventional-tillage and no-tillage systems, when planted at weekly intervals and sampled four times during the seedling stage.

MATERIALS AND METHODS

Test design

Field studies were initiated in the spring of 1995 at Brooksville and Raymond, MS. These locations represent two of the primary soil types in the state that support maize production. The site at Brooksville had a Brooksville silty clay (Aquic, chromuderts, fine, Montmorillonitic thermic) with slow permeability and poor drainage, and the site at Raymond had a Memphis silt loam (fine-silty, mixed thermic, Typic haplaudalfs) with moderate permeability and good drainage. A split-plot arrangement of treatments with whole plots randomized four times in a complete block design was used each yr at each location with each plot containing randomized subplots. Plots were either tilled with a do-all and rows formed in the fall, or were left undisturbed until planting in the spring; subplots were eight rows 6 m long and 6.09 m wide from which seedlings were harvested 3, 10, 17 or 28 d after planting. The previous crop at each location was soybean.

Maize seeds of the hybrid, Pioneer 3167 treated with captan, were planted in each subplot at the rate of 10 500 kernels ha⁻¹ at Brooksville and 8500 kernels ha⁻¹ at Raymond, with 81 cm between rows at Brooksville and 95 cm at Raymond. Plots were fertilized according to soil test recommendations. At Brooksville, preplant 13-13-13 (N-P-K) (336 kg ha⁻¹) and lime (3 mt ha⁻¹) was used and at Raymond 0-0-60 (112 kg ha⁻¹) was used. Nitrogen was sidedressed at 90 kg ha⁻¹ at Brooksville and at 146 kg ha⁻¹ at Raymond. Weeds were controlled by cultivation or herbicides in

the conventional-till plots, and by herbicides only in the no-till plots. For conventional-till plots, the pre-emergence application consisted of atrazine (4.7 L ha⁻¹ at Brooksville and 3.5 L ha⁻¹ at Raymond), alachlor at Brooksville (7.0 L ha⁻¹) and metolachlor at Raymond (2.3 L ha⁻¹), and paraquat (2.3 L ha⁻¹) for the no-till plots at both locations.

Sample collection and fungal isolation

Maize seedlings, with roots and contiguous soil, were lifted with a shovel at 3, 10, 17, and 28 d after planting. Ten seedlings were randomly sampled from each of four rows. Roots were separated from seedlings, washed in running tap water, and observed for water-soaked or discolored areas. Portions of roots with lesions were excised, surface-disinfested for 1 min in 0.5% NaOCl, rinsed for 1 min in sterile distilled water, blotted dry on sterile filter paper, and incubated for 48 h on water agar at room temperature (26°C). Hyphal tips of suspected colonies of *Fusarium* spp. were transferred to potato dextrose agar (Difco) supplemented with streptomycin (50 mg L⁻¹) and aureomycin (30 mg L⁻¹) (PDASA). After 3 d, colonies with morphological characters of *Fusarium* spp. were transferred to potato dextrose agar (PDA) prepared from fresh potatoes and onto carnation leaf agar (CLA) (Nelson *et al.* 1983), and were incubated 3 to 7 d at room temperature for identification.

A 100 g sample of rhizosphere soil was collected from the area adjacent to roots of maize seedlings. *Fusarium* spp. were isolated from rhizosphere soil samples during the 1996 and 1997 growing seasons. Soil was air-dried for 24 h and then sieved through a 20-mesh screen. A modified Nash-Snyder medium (NSM) (Nash and Snyder 1965), semi-selective for *Fusarium* spp., was prepared by adding streptomycin sulfate and neomycin sulfate (0.1% and 0.02%, respectively) to the autoclaved basal medium after it cooled to 50°C. One g of dry soil was mixed with 100 mL of sterile, distilled water in a beaker and stirred on a magnetic stirrer. One mL of this suspension was withdrawn in a pipette and dispensed into a petri plate

containing NSM, then spread with a bent glass rod. Plates were incubated in the dark at 28°C for 2 d and then placed under fluorescent light (1700 lux) in the laboratory. Colonies of fungi resembling *Fusarium* spp. growing from soil particles were counted. Hyphal tips of these colonies were transferred to PDASA for further identification. Populations were expressed as colony-forming units per g of dried soil (cfu g⁻¹).

Identification of *Fusarium* spp.

Identification of *Fusarium* spp. from seedling root tissues was based upon the descriptions of Nelson *et al.* (1983). Isolates were cultured on CLA for 1 wk under fluorescent light in the laboratory at room temperature for the observation of morphological characteristics and measurement of macroconidia. Isolates also were grown on PDA for the observation of cultural characteristics. Isolates identified as *F. solani* were further characterized into form A or B using the descriptions of Killebrew *et al.* (1988, 1993) and Roy (1997). Macroconidial dimensions were recorded for isolates grown on modified Bilay's medium (Booth 1977) for 1 wk under fluorescent light in the laboratory.

Pathogenicity tests

Laboratory tests for the effect of *F. moniliforme* on growth of maize seedling roots were conducted using a technique adapted from Futrell and Kilgore (1969). Pure cultures of *F. moniliforme* isolated from maize roots were grown on Czapek's agar medium in 9-cm-diam petri plates until mycelium covered the agar surface. Kernels of Pioneer 3167 were surface sterilized for 1 min in 0.5% NaOCl and were placed on actively growing cultures for 4 d. Ten germinating kernels that were covered with mycelial growth then were placed into five 250 mL flasks (two kernels per flask) containing Czapek's medium and were incubated under fluorescent light in the laboratory. Surface sterilized kernels, not previously exposed to *F. moniliforme*, also were grown in Czapek's medium. After 8 d, seedlings had reached the top of the flask and plants were harvested. The number of devel-

oping secondary roots and length of primary roots were determined.

Due to common rotation of maize and soybean, pathogenicity of *F. solani* isolates from maize roots was tested to determine effects on maize and soybean germination and dry weight accumulation of maize roots. Inoculum was prepared by blending 100 mL of distilled water with a culture of *F. solani* growing on a plate of PDA. Twenty-five mL of inoculum suspension was mixed into methyl bromide-fumigated soil (1:1 sand:soil, v:v) in 15-cm-diam clay pots in the greenhouse. Five untreated soybean seeds, cultivar Tracy M, were planted 2.5 cm deep in each pot in the soybean test. For the maize test, the experiment was divided into three treatments: captan-treated Pioneer 3167 kernels grown in fumigated soil, fungicide-treated kernels grown in soil infested with *F. solani*, and kernels with fungicide removed grown in infested soil (Bacon *et al.* 1994). Five kernels were planted in each pot, and pots were arranged randomly in three replications with three pots in a replication. Seedlings of maize and soybean were counted one wk after planting. Four wk after planting, seedling roots of maize were separated from shoots, washed free of soil, and dried to a constant weight in a drying oven. The pathogenicity experiment was repeated once.

Data analysis

Data were analyzed using the General Linear Model (GLM) procedure of SAS (SAS Institute Inc., Cary, NC) to evaluate effects of location, tillage, production yr, planting date, sampling times, and interactions between these factors, on the occurrence of *Fusarium* spp. in maize roots and rhizosphere soil. Data from pathogenicity tests also were subjected to analysis of variance. Percentage data were subjected to arcsine transformation prior to analysis, and non-transformed means are reported. If treatments were significantly different, means were separated using Fisher's protected least significant difference procedure ($P \leq 0.05$).

RESULTS

Fusarium spp. from maize seedling roots

Based on analysis of variance for the frequency of isolation of *Fusarium* spp. from root tissues, tillage ($P = 0.0206$), planting date ($P = 0.0120$), and sampling time ($P = 0.0293$) were significant main effects for the occurrence of these fungi. Because locations (soil type) and yr of production were not significant main effects, these data were combined, and two-factor analyses of variance were performed for effects of planting date and sampling time in each tillage system. Under conventional tillage, *Fusarium* spp. were isolated most frequently at the earliest and the latest planting dates (Table 1). *Fusarium* spp. were also more frequent when plants were sampled 10 and 17 d after planting. Statistically, there were exceptions to these results. In no-tillage plots the overall frequency of isolation was lower and tended to decrease with later planting dates and sampling times.

Fusarium spp. from rhizosphere soil

There was a highly significant five-way interaction ($P = 0.0001$) among location, yr of production, tillage system, planting date and sampling time for *Fusa-*

rium spp. from the rhizosphere soil of maize seedlings. The population of *Fusarium* spp. in the maize rhizosphere was numerically higher in Raymond than in Brooksville, especially in conventional-tillage plots in 1997 (Table 2).

Identification of *Fusarium* spp.

Ten *Fusarium* spp. were identified during 1996 and 1997. They were *F. acuminatum* Ellis & Everh., *F. aquaeductum* (Radlk. & Rabenh.) Lagerh., *F. decemcellulare* C. Brick, *F. equiseti* (Corda) Sacc., *F. heterosporum* Nees:Fr., *F. moniliforme*, *F. oxysporum*, *F. poae* (Peck) Wollenweb., *F. semitectum* Berk. & Ravenel, and *F. solani*. *Fusarium moniliforme* was the predominant *Fusarium* sp. recovered from rhizosphere soil of maize and represented 45% of the total population of *Fusarium* spp. It also was the predominant *Fusarium* sp. isolated from maize seedling roots (52% of all *Fusarium* spp. isolated), followed by *F. solani* (14%) and *F. oxysporum* (13%).

Isolates of *F. solani* were further identified as form B based on colony and microscopic morphological characteristics similar to those described by Roy (1997). These isolates had white floccose aerial mycelial growth, and microconidia were abundant. Microconidio-

Table 1. Effects of planting date and days after planting on the frequency of isolation (%) of *Fusarium* spp. from roots of Pioneer 3167 hybrid maize seedlings grown at Brooksville and Raymond, MS over three seasons (1995 to 1997) under conventional-tillage and no-tillage treatments

Planting date ^a	Frequency of isolation (%) of <i>Fusarium</i> spp. per tillage and days after planting							
	Conventional-tillage				No-tillage			
	3	10	17	28	3	10	17	28
1	4 Ab ^b	22 Aa	8 Bb	5 Ab	11 Aab	12 Aa	8 Aab	4 Bb
2	6 Aa	10 BCa	7 Ba	6 Aa	9 Aa	3 BCb	3 Bb	3 Bb
3	4 Aa	5 Ca	5 Ba	7 Aa	9 Aa	0 Cb	5 ABab	11 Aa
4	4 Ab	14 Ba	16 Aa	10 Aa	6 Aa	8 ABa	3 Ba	3 Ba

^a Planting dates for the two locations began on the first date permitted by soil moisture conditions during the recommended time period for the region of the state and continued on a weekly basis for 4 wk for the 3 yr of the study.

^b Means (among planting dates within a sampling time, or among sampling times within a planting date, for a tillage method) followed by the same letter (column = uppercase; row = lowercase) are not significantly different at $P \leq 0.05$ according to Fisher's protected least significant difference test.

Table 2. Effects of location, year of production, tillage system, planting date, and sampling time on the population of *Fusarium* spp. isolated from the rhizosphere of Pioneer 3167 hybrid maize seedlings grown at Brooksville and Raymond, MS in 1996 and 1997

Colony-forming units per g of dried soil																
	Conventional-tillage 1996				No-tillage 1996				Conventional-tillage 1997				No-tillage 1997			
	S3 ^a	S10	S17	S28	S3	S10	S17	S28	S3	S10	S17	S28	S3	S10	S17	S28
Brooksville ^b																
D1	6Aa ^c	4Ba	3Ca	2Ba	0Ca	0Ba	1Ba	1Aa	3Bb	8Aa	0Cb	2Ab	12Aa	9Aa	10Aa	9Aa
D2	8Ab	7Ab	8Ab	13Aa	3Ba	0Bb	3ABa	2Aab	0Bb	4Aa	2Bab	2Aab	6Ba	4Bb	3Bb	3Bb
D3	5Aa	5ABa	7ABa	3Ba	6Aa	6Aa	5Aa	3Aa	7Aa	3Bb	4ABab3Ab		2Ca	2Ba	1Ba	2Ba
D4	5Aa	5ABa	4BCab2Bb		3Bb	8Aa	3ABb	2Ab	9Aa	4Ab	5Ab	2Ab	12Aa	12Aa	10Aa	11Aa
Raymond ^b																
D1	17Aa	17Aa	13Aa	12Aa	10Aab	12Aa	5Bb	9Aab	18Ba	25Aa	28Aa	19Ba	17Ba	18Aa	17Aa	13Aa
D2	8BCa	7Ba	6BCa	7Ba	5Ba	5Ba	6ABa	4Ba	32Aab	24Ab	13Bc	33Aa	32Aa	17Ab	8Bbc	5Bc
D3	10Ba	4Bb	3Cb	3Bb	12Aab	17Aa	10Ab	9Ab	12Ba	8Bab	4Cb	4Cb	6Cab	4Bbc	9Ba	1Cc
D4	5Cbc	7Bab	9ABa	3Bc	5Ba	5Ba	5Ba	1Cb	15Ba	7Bb	14Ba	15Ba	10Bab	12Aa	8Bab	6Bb

^a Samples were collected at 3, 10, 17 and 28 d after planting.

^b Planting dates for Brooksville ranged from 4/2 to 4/29 and for Raymond from 4/1 to 5/5 over the 2 yr of the study.

^c Comparisons were made within each site. Means (among sampling times within a planting date, or among planting dates within a sampling time, for a tillage method in a year) followed by the same letter (column = uppercase; row = lowercase) are not significantly different at $P \leq 0.05$ according to Fisher's protected least significant difference test.

phores were long, and several were more than 100 μm in length. Macroconidial length was shorter than the length of macroconidia of *F. solani* form A (Table 3).

Pathogenicity tests

In laboratory pathogenicity tests, *F. moniliforme* reduced the length of primary roots and the number of secondary roots of maize seedlings. The average length of primary roots of inoculated plants was only 3 cm, whereas roots of uninoculated controls averaged 14 cm. The mean number of secondary roots of inoculated plants was three, which was half that of untreated plants.

There was no reduction in seedling emergence in greenhouse tests when soil was infested with *F. solani*; emergence was 100% in soil infested with, or free of, the fungus. The fungus did significantly ($P < 0.05$) reduce the dry weight of maize roots when seedlings were grown from kernels where the fungicide was removed. The dry weight of seedlings in this treatment was 0.6 g,

compared to 1.5 g for seedlings growing from fungicide-treated kernels in sterile soil and 1.4 g for seedlings growing from fungicide-treated kernels in infested soil. Seedlings growing in infested soil from kernels with fungicide removed were at least 15 cm shorter than seedlings growing from fungicide-treated kernels in fumigated soil. Emergence of soybeans grown in soil infested with *F. solani* was 29% compared to a germination of 96% in fumigated soil.

DISCUSSION

Our study confirms that isolation frequency of *Fusarium* spp. on maize seedlings is influenced by tillage practice and that population densities of these fungi are affected by planting date and seedling growth stage at the time of sampling in Mississippi. Maize seedling roots in the current study were initially colonized more in no-tillage plots by *Fusarium* spp.; this changed between 3 and 10 d after planting when

Table 3. Dimensions of macroconidia of *Fusarium solani* isolates from roots of maize seedlings compared to known isolates of *F. solani* form A (FSA) and form B (FSB)

Isolate	Macroconidial dimensions ^a			
	Length (μm)		Width (μm)	
	Mean	Range	Mean	Range
S12P7 (FSA) ^b	41	33-45	4.4	4.0-5.5
FSA Lee ^b	45	38-55	4.6	4.0-5.0
FSB Harry - 1 ^b	32	23-36	4.5	4.0-5.0
96BNT312 ^c	32	29-34	4.1	4.0-5.0
XNT440 ^c	32	31-38	4.7	4.0-5.0
96RT442 ^d	32	28-34	4.2	4.0-5.0

^a Twenty-five conidia measured per isolate after growth on modified Bilay's medium for 7 d at 25°C under continuous fluorescent light.

^b Isolates from Dr. K.W. Roy, Mississippi State University, Starkville, MS.

^c Isolate 96BNT312 from maize grown in Brooksville, 1996; XNT440 from Brooksville, 1997.

^d Isolate 96RT442 from maize grown in Raymond, 1996.

root tissues were colonized more under conventional-tillage. This finding is similar to observations by Miller (1963) who reported a seasonal fluctuation in *F. moniliforme* in the maize rhizosphere with a maximum frequency at 6 d after planting.

When maize was grown on the silt loam soil at Raymond, the population of *Fusarium* spp. was higher in conventional-tillage plots than in no-tillage plots in both yr; on the silty clay at Brooksville, the population of *Fusarium* spp. was higher in conventional-tillage plots in 1996 but not in 1997. In contrast, total *Fusarium* populations in wheat fields in North Dakota were similar under conventional and reduced tillage (3266 and 3124 cfu g⁻¹ soil, respectively; Salas and Stack 1991). Lipps and Deep (1991) reported that the total percentage of *Fusarium* spp. from sub-crown mesocotyls and crowns of maize was statistically higher under no-tillage conditions than when fields were fall-plowed, but this effect varied with growing season.

We previously reported the isolation of several fungal species from maize seedlings from Brooksville and Raymond, MS (Barrera and Trevathan 1997). *Trichoderma* spp. were isolated most frequently; *Fusarium* spp. were the second most frequent fungi, and *F. moniliforme* was the most common

species. In the current study, *F. moniliforme*, *F. solani* and *F. oxysporum* were the predominant *Fusarium* spp. isolated from maize seedling roots. In a similar study with maize in Florida, the same three species also were predominant (Young and Kucharek 1977). In Texas, *Fusarium* spp. isolated from maize roots and stalks increased with crop maturity (Ring and Odvody 1990), but this was not observed with either tillage system or on either soil type in our study with maize seedlings. *Fusarium* root disease of maize seedlings is important for several reasons, including reported associations between root and stalk rots (McKeen 1953; Wall and Mortimore 1965; Whitney and Mortimore 1957; Williams and Schmitthenner 1963; Windels 1992). Whitney and Mortimore (1957) considered these two diseases to be successive phases of one disease.

In pathogenicity tests with *F. moniliforme*, symptoms were visible as reddish discoloration of the young primary root and secondary roots, and isolates of *F. moniliforme* also reduced the length of primary roots. Several researchers have reported the ability of this species to invade maize plants and grow systemically without causing symptoms; such infection has been reported to progress into the kernels (Bacon *et al.* 1994; Kedera *et al.* 1992, 1994; Munkvold *et al.* 1997; Thomas and

Buddenhagen 1980). Therefore, this fungus can be internal in symptomless, apparently healthy maize kernels, and infection could spread from kernel to kernel (Kedera *et al.* 1994; Valteau 1920; Warren and Kommedahl 1973). MacDonald and Chapman (1997) found *Fusarium* spp. to be the largest group of fungi isolated from maize kernels in Central America, Africa and Asia, and *F. moniliforme* was the most frequent species. Ocamb *et al.* (1989) reported that seedling root systems emerging from maize kernels that were coated with *Fusarium* spp. were extensively colonized by *F. moniliforme* (90%) and *F. oxysporum* (39%). They concluded that *Fusarium* spp. present in the seeds differed as potential inoculum sources for maize root infection under field conditions. Ochor *et al.* (1987) found kernel infection with *F. moniliforme* to have little influence on germination. This may mean that the most important source of inoculum for this species is soilborne.

The populations of *Fusarium* spp. in rhizosphere soil at Brooksville and Raymond were influenced by the interaction of the factors assayed in the study. However, no trends were found. *Fusarium moniliforme* was isolated most frequently from the rhizosphere of maize and represented 45% of the total population of *Fusarium* spp. In a 10 yr study in Minnesota, Warren and Kommedahl (1973) reported that *F. moniliforme* isolated from maize residues or soil never comprised more than 4% of the total *Fusarium* spp., and increased residue retention in minimum tillage did not increase the inoculum potential of *Fusarium* spp. Their results were based on continuous cropping of maize. Leslie *et al.* (1990) also considered *F. moniliforme* a minor component of *Fusarium* populations surviving in maize residues. In our study, experimental plots were previously cropped to soybean. Thus, cropping history may be an important factor in the prevalence of a specific *Fusarium* sp. in a population.

Since maize is grown in rotation with soybean in Mississippi, the fact that *F. solani* was the second most frequently isolated *Fusarium* spp. may be signifi-

cant in the epidemiology of diseases incited by this fungus on soybean. *Fusarium solani* isolates from maize seedling roots and rhizosphere soil in this study were all form B, which is known to cause seed rot of soybean. The frequent isolation of *F. solani* from maize seedling roots confirms the ability of the fungus to survive in a nonhost as a saprophyte or weak pathogen. Schroth and Hendrix (1962) suggested that survival of *Fusarium solani* f. sp. *phaseoli* (Burkholder) W. C. Snyder and H. N. Hans. in agricultural land is enhanced by temporary supplies of nutrients in diffusate from nonsusceptible plants and crop residues that enable the fungus to form chlamydospores. Ocamb and Kommedahl (1994) reported that *F. moniliforme* survived most readily in soil to a depth of 30 cm, and survival increased from the soil surface to that depth. Most seedlings collected in our study were in vegetative stage 1 as defined by Foth (1962). Since all samples were removed and inspected from 3 to 28 d after planting, seedling roots were within the zone of reportedly high concentration of *F. moniliforme*. Populations of *Fusarium* spp. on maize at Brooksville and Raymond were higher than those reported from wheat by Salas and Stack (1991) and higher than the reported threshold for *F. moniliforme* on sorghum in Mississippi. Only Pioneer 3167 was used in this study, and results with other hybrids may vary or be different from those reported here.

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